Building Your Wi-Fi Capacity

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IT Manager
Winton Woods City Schools

Certified Wireless Network Administrator

- Wi-Fi
- G Suite & Chromebooks
- Virtualization
- Help Desk Management
- Process Automation / Scripting
- Access Control & Surveillance

The Best Way to Build Capacity

Training: Certified Wireless Network Professionals certifications - Vendor neutral based on job role requirements.

Wi-Fi Conferences:

- Wi-Fi Trek
- Wireless LAN Professionals Conference

Be Part of the Wi-Fi Community!
Twitter (#WLPC), Blogs, YouTube (WPLC, CWNP), Podcasts

Our Project

A real DIY project:

- Keep labor costs low: Leveraging our in-house skillset. Install labor only.
- eRate process and timeline didn't allow for much else.

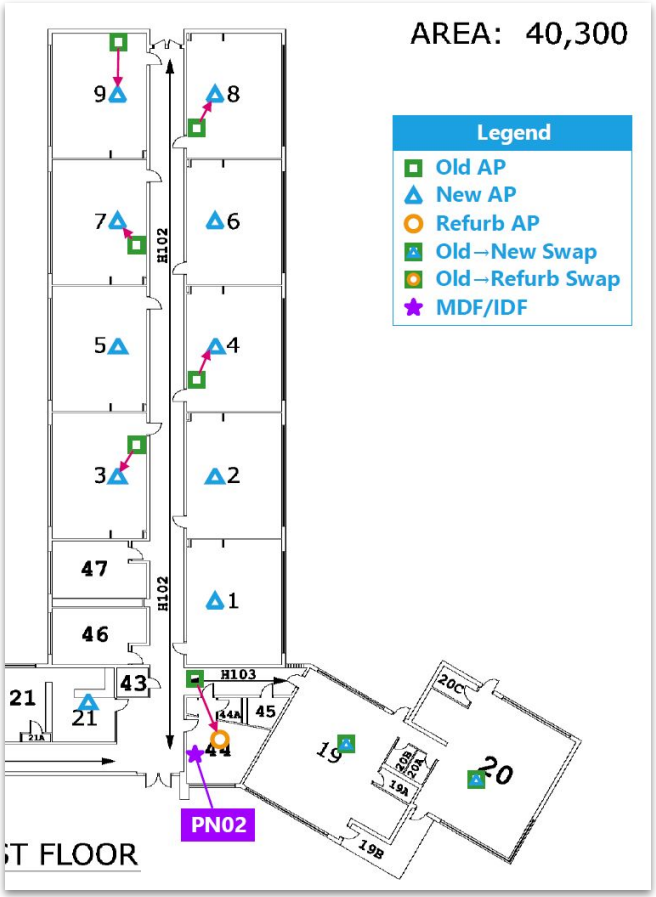
We already knew where our deficient areas were and could troubleshoot / remediate ourselves.

🚩 **Vendors using any kind of guideline.** Advice like "1 AP per room *or square foot*" or "30 devices per AP," etc. should be concerning. Wi-Fi often works *despite* a poor design.

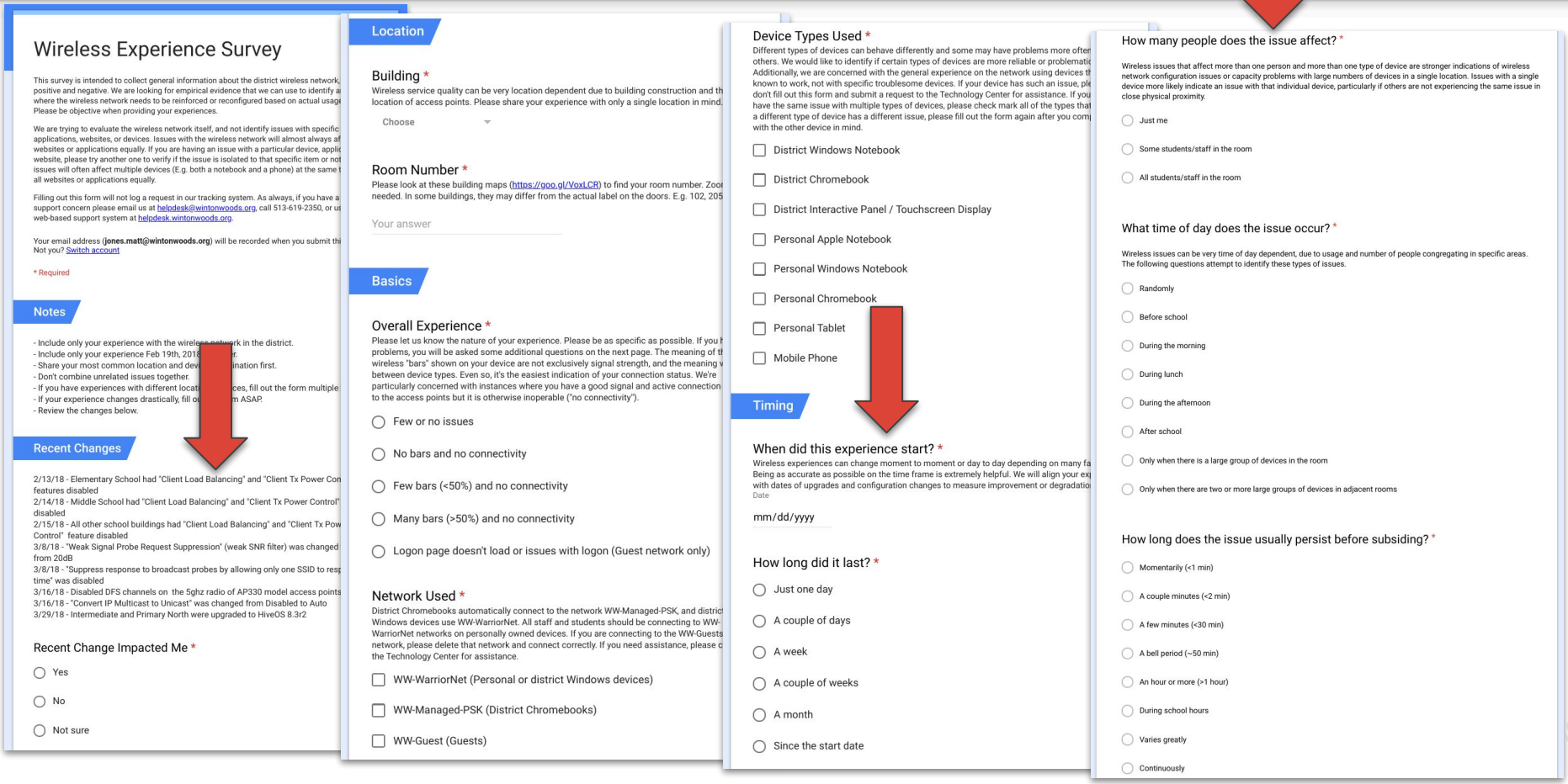
Project Tracking Sheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	T	U	V	W	X	Y
1	Location						New AP							Existing AP				Switch Port		Progress			
2	Blc	Flc	Roc	Al	AH M	Room	Name	Box	Mode	Serial	MAC	Asset #	Destiny	Name	Mod	Serial	MAC	Switch/IDF	Port	Cabli	Onlin	Switc	Local
3	PN	1FL	1		PN-1FL	PN-1	AH-PN001	1	AP550	05501707051	B87CF253E6	007864	90013332	N/A				PN02-2920-62	38	Y	Y	Y	
4	PN	1FL	2		PN-1FL	PN-2	AH-PN002	2	AP550	05501707051	B87CF253E2	007865	90013333	N/A				PN02-2920-62	34	Y	Y	Y	
5	PN	1FL	3		PN-1FL	PN-3	AH-PN003	3	AP550	05501707051	B87CF253E4	007866	90013334	AH-PN003	AP121	12113070100297	4018B1926280	PN02-2920-62	42	N/A	Y	Y	
6	PN	1FL	4		PN-1FL	PN-4	AH-PN004	4	AP550	05501707051	B87CF253E8	007867	90013335	AH-PN004	AP121	12113070100182	4018B19244C0	PN02-2920-62	45	N/A	Y	Y	
7	PN	1FL	5		PN-1FL	PN-5	AH-PN005	5	AP550	05501707051	B87CF253E7	007868	90013336	N/A				PN02-2920-62	35	Y	Y	Y	
8	PN	1FL	6		PN-1FL	PN-6	AH-PN006	6	AP550	05501707051	B87CF253E6	007869	90013337	N/A				PN02-2920-62	36	Y	Y	Y	
9	PN	1FL	7		PN-1FL	PN-7	AH-PN007	7	AP550	05501707051	B87CF253D6	007870	90013338	AH-PN007	AP121	12113062800059	4018B1921580	PN02-2920-62	43	N/A	Y	Y	
10	PN	1FL	8		PN-1FL	PN-8	AH-PN008	8	AP550	05501707051	B87CF253E4	007871	90013339	AH-PN008	AP121	12113070100013	4018B1921AC0	PN02-2920-62	48	N/A	Y	Y	
11	PN	1FL	9		PN-1FL	PN-9	AH-PN009	9	AP550	05501707051	B87CF253DD	007872	90013340	AH-PN009	AP121	12114061902925	F09CE91E1200	PN02-2920-62	40	N/A	Y	Y	
12	PN	1FL	11		PN-1FL	PN-11	AH-PN011	10	AP550	05501707051	B87CF253E8	007873	90013341	N/A				PN01-2910al-60	35	Y	Y	Y	
13	PN	1FL	12		PN-1FL	PN-12	AH-PN012	11	AP550	05501707051	B87CF253E3	007874	90013342	AH-PN012	AP121	12113070100100	4018B1923000	PN01-2910al-60	34	N/A	Y	N-W-IDF	
14	PN	1FL	13		PN-1FL	PN-13	AH-PN013	12	AP550	05501707051	B87CF253E5	007875	90013343	AH-PN013	AP121	12113070100286	4018B1925CC0	PN01-2910al-60	33	N/A	Y	N-W-IDF	
15	PN	1FL	14		PN-1FL	PN-14	AH-PN014	13	AP550	05501707051	B87CF253DF	007876	90013344	N/A				PN01-2910al-60	36	Y	Y	Y	
16	PN	1FL	15		PN-1FL	PN-15	AH-PN015	14	AP550	05501707051	B87CF253E7	007877	90013345	N/A				PN01-2910al-60	37	Y	Y	Y	
17	PN	1FL	16		PN-1FL	PN-16	AH-PN016	15	AP550	05501707051	B87CF253E9	007878	90013346	AH-PN016	AP121	12113070100305	4018B1926080	PN01-2910al-60	32	N/A	Y	N-W-IDF	
18	PN	1FL	17		PN-1FL	PN-17	AH-PN017	16	AP550	05501707051	B87CF253DD	007879	90013347	AH-PN017	AP121	12113070100326	4018B1926A40	PN01-2910al-60	44	N/A	Y	Y	
19	PN	1FL	18		PN-1FL	PN-18	AH-PN018	17	AP550	05501707051	B87CF253DF	007880	90013348	N/A				PN01-2910al-60	38	Y	Y	Y	
20	PN	1FL	19		PN-1FL	PN-19	AH-PN019	18	AP550	05501707051	B87CF253E0	007881	90013349	AH-PN019	AP121	12113070100032	4018B1921F80	PN02-2920-62	44	N/A	Y	Y	
21	PN	1FL	20		PN-1FL	PN-20	AH-PN020	19	AP550	05501707051	B87CF25432	007882	90013350	AH-PN020	AP121	12114061903017	F09CE91E2900	PN02-2920-62	41	N/A	Y	Y	
22	PN	1FL	21		PN-1FL	PN-21	AH-PN021	20	AP550	05501707051	B87CF25432	007883	90013351	N/A				PN02-2920-62	37	Y	Y	Y	
23	PN	1FL	22		PN-1FL	PN-22	AH-PN022	21	AP550	05501707051	B87CF25434	007884	90013352	AH-PN022	AP121	12113070100302	4018B1926140	PN02-2920-62	46	N/A	Y	Y	
24	PN	1FL	25	A	PN-1FL	PN-25	AH-PN025-A	22	AP550	05501707051	B87CF25442	007885	90013353	AH-PN025	AP330	33013052000470	E01C41222980	PN01-2910al-60	25	N/A	Y	N-W-IDF	
25	PN	1FL	25	B	PN-1FL	PN-25	AH-PN025-B	23	AP550	05501707051	B87CF25438	007886	90013354	N/A				PN01-2910al-60	31	N-F	N-F	N-W-Ver	
26	PN	1FL	28		PN-1FL	PN-28	AH-PN028	24	AP550	05501707051	B87CF25433	007887	90013355	AH-PN028	AP121	12113070100284	4018B1925D40	PN01-2910al-60	30	N/A	Y	N-W-IDF	

Installation Maps



User Experience Survey



Wireless Experience Survey

This survey is intended to collect general information about the district wireless network, positive and negative. We are looking for empirical evidence that we can use to identify a where the wireless network needs to be reinforced or reconfigured based on actual usage Please be objective when providing your experiences.

We are trying to evaluate the wireless network itself, and not identify issues with specific applications, websites, or devices. Issues with the wireless network will almost always af websites or applications equally. If you are having an issue with a particular device, applic website, please try another one to verify if the issue is isolated to that specific item or not issues will often affect multiple devices (E.g. both a notebook and a phone) at the same t all websites or applications equally.

Filling out this form will not log a request in our tracking system. As always, if you have a support concern please email us at helpdesk@wintonwoods.org, call 513-619-2350, or us web-based support system at helpdesk.wintonwoods.org.

Your email address (**jones.matt@wintonwoods.org**) will be recorded when you submit thi Not you? Switch account

* Required

Notes

- Include only your experience with the wireless network in the district.
- Include only your experience Feb 19th, 201
- Share your most common location and dev ination first.
- Don't combine unrelated issues together.
- If you have experiences with different locat ces, fill out the form multiple
- If your experience changes drastically, fill ou m ASAP.
- Review the changes below.

Recent Changes

2/13/18 - Elementary School had "Client Load Balancing" and "Client Tx Power Con features disabled
2/14/18 - Middle School had "Client Load Balancing" and "Client Tx Power Control" disabled
2/15/18 - All other school buildings had "Client Load Balancing" and "Client Tx Pow Control" feature disabled
3/8/18 - "Weak Signal Probe Request Suppression" (weak SNR filter) was changed from 20dB
3/8/18 - "Suppress response to broadcast probes by allowing only one SSID to resp time" was disabled
3/16/18 - Disabled DFS channels on the 5ghz radio of AP330 model access points
3/16/18 - "Convert IP Multicast to Unicast" was changed from Disabled to Auto
3/29/18 - Intermediate and Primary North were upgraded to HiveOS 8.3r2

Recent Change Impacted Me *

- Yes
- No
- Not sure

Location

Building *

Wireless service quality can be very location dependent due to building construction and th location of access points. Please share your experience with only a single location in mind.

Choose

Room Number *

Please look at these building maps (https://goo.gl/VoxLCR) to find your room number. Zoo needed. In some buildings, they may differ from the actual label on the doors. E.g. 102, 205

Your answer

Basics

Overall Experience *

Please let us know the nature of your experience. Please be as specific as possible. If you h problems, you will be asked some additional questions on the next page. The meaning of th wireless "bars" shown on your device are not exclusively signal strength, and the meaning v between device types. Even so, it's the easiest indication of your connection status. We're particularly concerned with instances where you have a good signal and active connection to the access points but it is otherwise inoperable ("no connectivity").

- Few or no issues
- No bars and no connectivity
- Few bars (<50%) and no connectivity
- Many bars (>50%) and no connectivity
- Logon page doesn't load or issues with logon (Guest network only)

Network Used *

District Chromebooks automatically connect to the network WW-Managed-PSK, and district Windows devices use WW-WarriorNet. All staff and students should be connecting to WW-WarriorNet networks on personally owned devices. If you are connecting to the WW-Guests network, please delete that network and connect correctly. If you need assistance, please c the Technology Center for assistance.

- [ ] WW-WarriorNet (Personal or district Windows devices)
- [ ] WW-Managed-PSK (District Chromebooks)
- [ ] WW-Guest (Guests)

Device Types Used *

Different types of devices can behave differently and some may have problems more often others. We would like to identify if certain types of devices are more reliable or problematic Additionally, we are concerned with the general experience on the network using devices th known to work, not with specific troublesome devices. If your device has such an issue, ple don't fill out this form and submit a request to the Technology Center for assistance. If you have the same issue with multiple types of devices, please check mark all of the types that a different type of device has a different issue, please fill out the form again after you comp with the other device in mind.

- [ ] District Windows Notebook
- [ ] District Chromebook
- [ ] District Interactive Panel / Touchscreen Display
- [ ] Personal Apple Notebook
- [ ] Personal Windows Notebook
- [ ] Personal Chromebook
- [ ] Personal Tablet
- [ ] Mobile Phone

Timing

When did this experience start? *

Wireless experiences can change moment to moment or day to day depending on many fa Being as accurate as possible on the time frame is extremely helpful. We will align your ex with dates of upgrades and configuration changes to measure improvement or degradatio

Date

mm/dd/yyyy

How long did it last? *

- Just one day
- A couple of days
- A week
- A couple of weeks
- A month
- Since the start date

How many people does the issue affect? *

Wireless issues that affect more than one person and more than one type of device are stronger indications of wireless network configuration issues or capacity problems with large numbers of devices in a single location. Issues with a single device more likely indicate an issue with that individual device, particularly if others are not experiencing the same issue in close physical proximity.

- Just me
- Some students/staff in the room
- All students/staff in the room

What time of day does the issue occur? *

Wireless issues can be very time of day dependent, due to usage and number of people congregating in specific areas. The following questions attempt to identify these types of issues.

- Randomly
- Before school
- During the morning
- During lunch
- During the afternoon
- After school
- Only when there is a large group of devices in the room
- Only when there are two or more large groups of devices in adjacent rooms

How long does the issue usually persist before subsiding? *

- Momentarily (<1 min)
- A couple minutes (<2 min)
- A few minutes (<30 min)
- A bell period (~50 min)
- An hour or more (>1 hour)
- During school hours
- Varies greatly
- Continuously

The “right” way to do Wi-Fi

1. **Requirements gathering:** Maps, materials, clients, applications.
2. **Site survey:** Predictive with attenuation mapping, or active AP on a stick site survey
3. **Installation & Configuration**
4. **Post-installation validation:**
    a. Site survey: Passive, active & spectrum
    b. RF tuning: Channel and power
    c. Association & authentication testing
    d. Roaming tests (if needed)
    e. Spectrum analysis (if needed)

🚩 **Skipping steps!** A quick 5-10 minute device discussion and a quick building tour is not sufficient.

🚩 **Post install reports can be deceiving.** The color gradient on post-install maps can be manipulated, and measurement tools may observe the network better than your devices.

Goals

- ☐ Provide airtime.
- ☐ Provide coverage.
- ☐ … but not too much.

Wi-Fi Capacity Planning

Some of my biggest “Aha!” moments of the last few years.

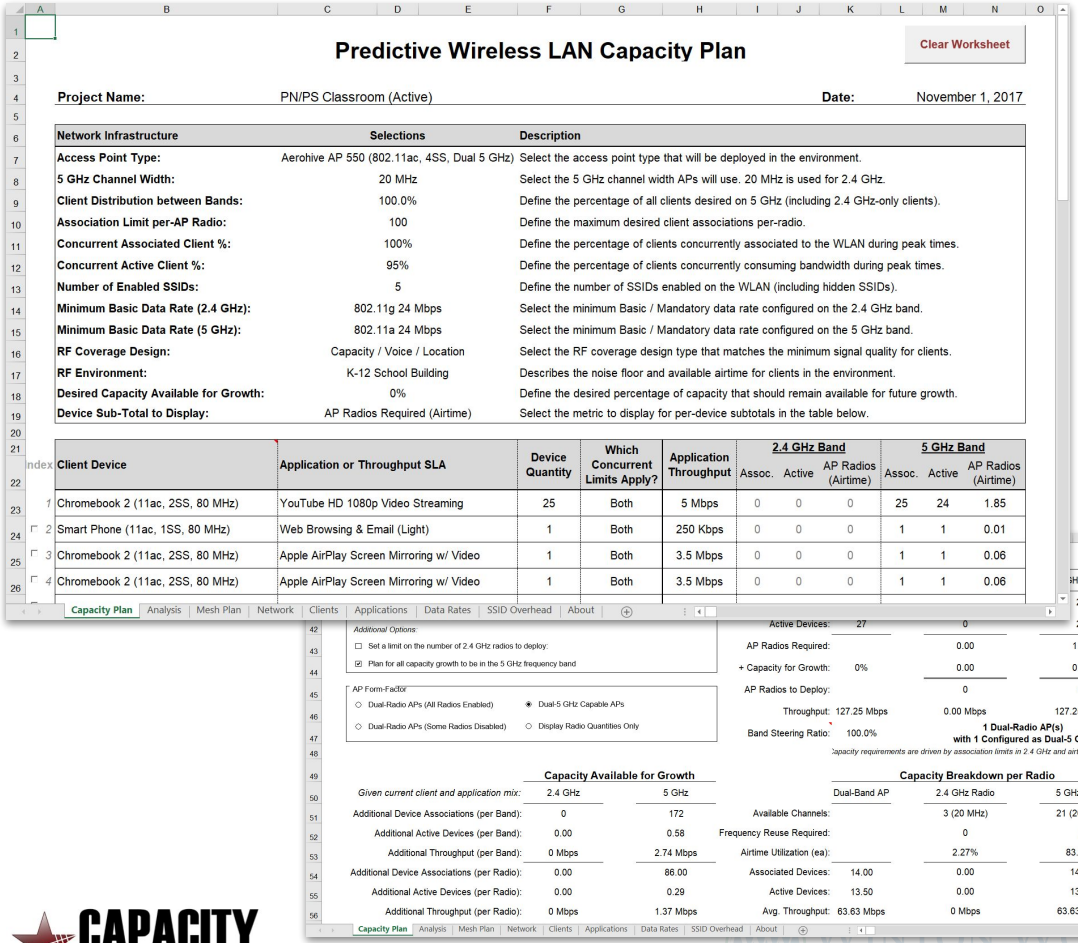
The Revolution Wi-Fi Capacity Planner

Warning: This **not** take into account physical floor plans.

1. **Interview your users!**
2. Break down the types of physical spaces, devices, and the applications used.
3. Do a reasonable capacity plan for each combination.

Let's experiment.

Where does the plan fall apart?



Predictive Wireless LAN Capacity Plan

Clear Worksheet

Project Name: PN/PS Classroom (Active) **Date:** November 1, 2017

Network Infrastructure	Selections	Description
Access Point Type:	Aerohive AP 550 (802.11ac, 4SS, Dual 5 GHz)	Select the access point type that will be deployed in the environment.
5 GHz Channel Width:	20 MHz	Select the 5 GHz channel width APs will use. 20 MHz is used for 2.4 GHz.
Client Distribution between Bands:	100.0%	Define the percentage of all clients desired on 5 GHz (including 2.4 GHz-only clients).
Association Limit per-AP Radio:	100	Define the maximum desired client associations per-radio.
Concurrent Associated Client %:	100%	Define the percentage of clients concurrently associated to the WLAN during peak times.
Concurrent Active Client %:	95%	Define the percentage of clients concurrently consuming bandwidth during peak times.
Number of Enabled SSIDs:	5	Define the number of SSIDs enabled on the WLAN (including hidden SSIDs).
Minimum Basic Data Rate (2.4 GHz):	802.11g 24 Mbps	Select the minimum Basic / Mandatory data rate configured on the 2.4 GHz band.
Minimum Basic Data Rate (5 GHz):	802.11a 24 Mbps	Select the minimum Basic / Mandatory data rate configured on the 5 GHz band.
RF Coverage Design:	Capacity / Voice / Location	Select the RF coverage design type that matches the minimum signal quality for clients.
RF Environment:	K-12 School Building	Describes the noise floor and available airtime for clients in the environment.
Desired Capacity Available for Growth:	0%	Define the desired percentage of capacity that should remain available for future growth.
Device Sub-Total to Display:	AP Radios Required (Airtime)	Select the metric to display for per-device subtotals in the table below.

Index	Client Device	Application or Throughput SLA	Device Quantity	Which Concurrent Limits Apply?	Application Throughput	2.4 GHz Band			5 GHz Band		
						Assoc.	Active	AP Radios (Airtime)	Assoc.	Active	AP Radios (Airtime)
1	Chromebook 2 (11ac, 2SS, 80 MHz)	YouTube HD 1080p Video Streaming	25	Both	5 Mbps	0	0	0	25	24	1.85
2	Smart Phone (11ac, 1SS, 80 MHz)	Web Browsing & Email (Light)	1	Both	250 Kbps	0	0	0	1	1	0.01
3	Chromebook 2 (11ac, 2SS, 80 MHz)	Apple AirPlay Screen Mirroring w/ Video	1	Both	3.5 Mbps	0	0	0	1	1	0.06
4	Chromebook 2 (11ac, 2SS, 80 MHz)	Apple AirPlay Screen Mirroring w/ Video	1	Both	3.5 Mbps	0	0	0	1	1	0.06

Capacity Plan | Analysis | Mesh Plan | Network | Clients | Applications | Data Rates | SSID Overhead | About

Additional Options:

Set a limit on the number of 2.4 GHz radios to deploy:

Plan for all capacity growth to be in the 5 GHz frequency band

AP Form-Factor

Dual-Radio APs (All Radios Enabled) — Dual-5 GHz Capable APs

Dual-Radio APs (Some Radios Disabled) — Display Radio Quantities Only

Active Devices:	27	0	27
AP Radios Required:		0.00	1.96
+ Capacity for Growth:	0%	0.00	0.00
AP Radios to Deploy:		0	2
Throughput:	127.25 Mbps	0.00 Mbps	127.25 Mbps
Band Steering Ratio:	100.0%	1 Dual-Radio AP(s) with 1 Configured as Dual-5 GHz	

Capacity requirements are driven by association limits in 2.4 GHz and airtime in 5 GHz

Capacity Available for Growth		
Given current client and application mix:	2.4 GHz	5 GHz
Additional Device Associations (per Band):	0	172
Additional Active Devices (per Band):	0.00	0.58
Additional Throughput (per Band):	0 Mbps	2.74 Mbps
Additional Device Associations (per Radio):	0.00	86.00
Additional Active Devices (per Radio):	0.00	0.29
Additional Throughput (per Radio):	0 Mbps	1.37 Mbps

Capacity Breakdown per Radio			
	Dual-Band AP	2.4 GHz Radio	5 GHz Radio
Available Channels:		3 (20 MHz)	21 (20 MHz)
Frequency Reuse Required:		0	1
Airtime Utilization (ea):		2.27%	83.24%
Associated Devices:	14.00	0.00	14.00
Active Devices:	13.50	0.00	13.50
Avg. Throughput:	63.63 Mbps	0 Mbps	63.63 Mbps

Capacity Plan | Analysis | Mesh Plan | Network | Clients | Applications | Data Rates | SSID Overhead | About

CAPACITY PLANNER

WINTON WOODS TECHNOLOGY CENTER

revolutionwifi.net/capacity-planner

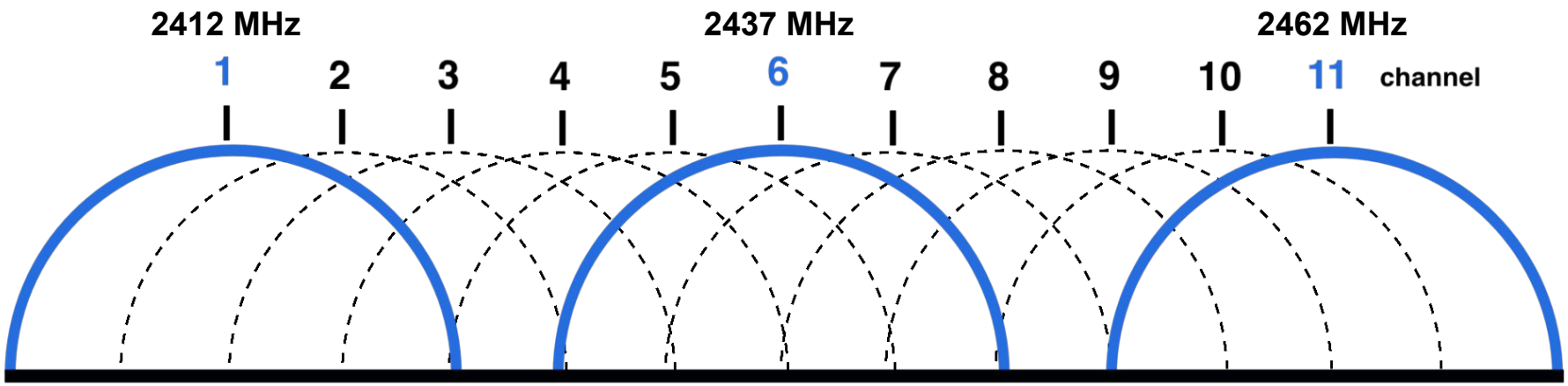
Spectrum is a limited, natural resource.

Vendor promises can’t beat physics.

But, new 802.11 amendments can make spectrum usage more efficient.

Wi-Fi Frequencies & Channels

2.4 GHz Spectrum - Channels 1, 6, and 11



5 GHz Spectrum

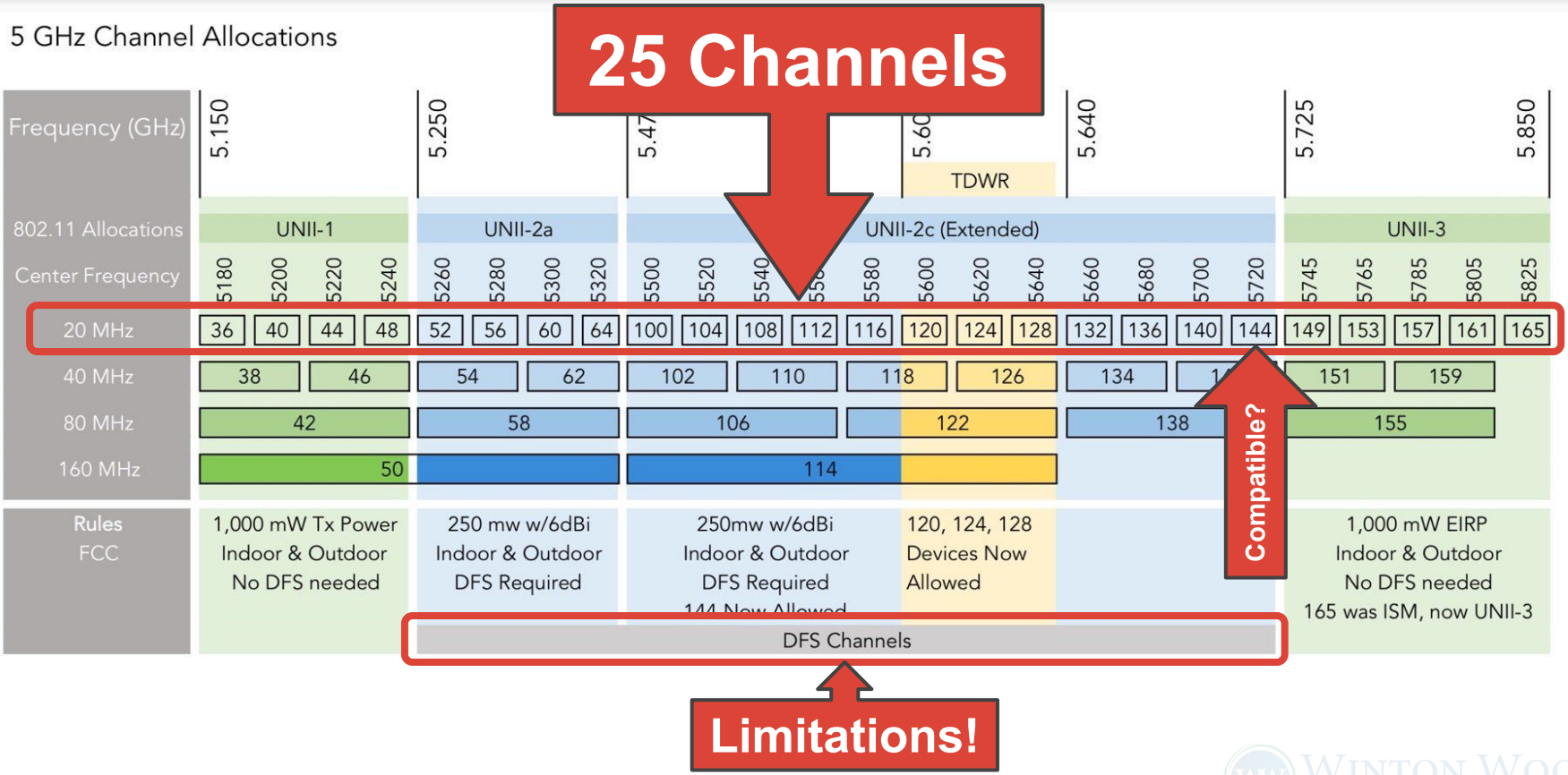


Image source: Keith R. Parsons, wlanpros.com

Channel Width

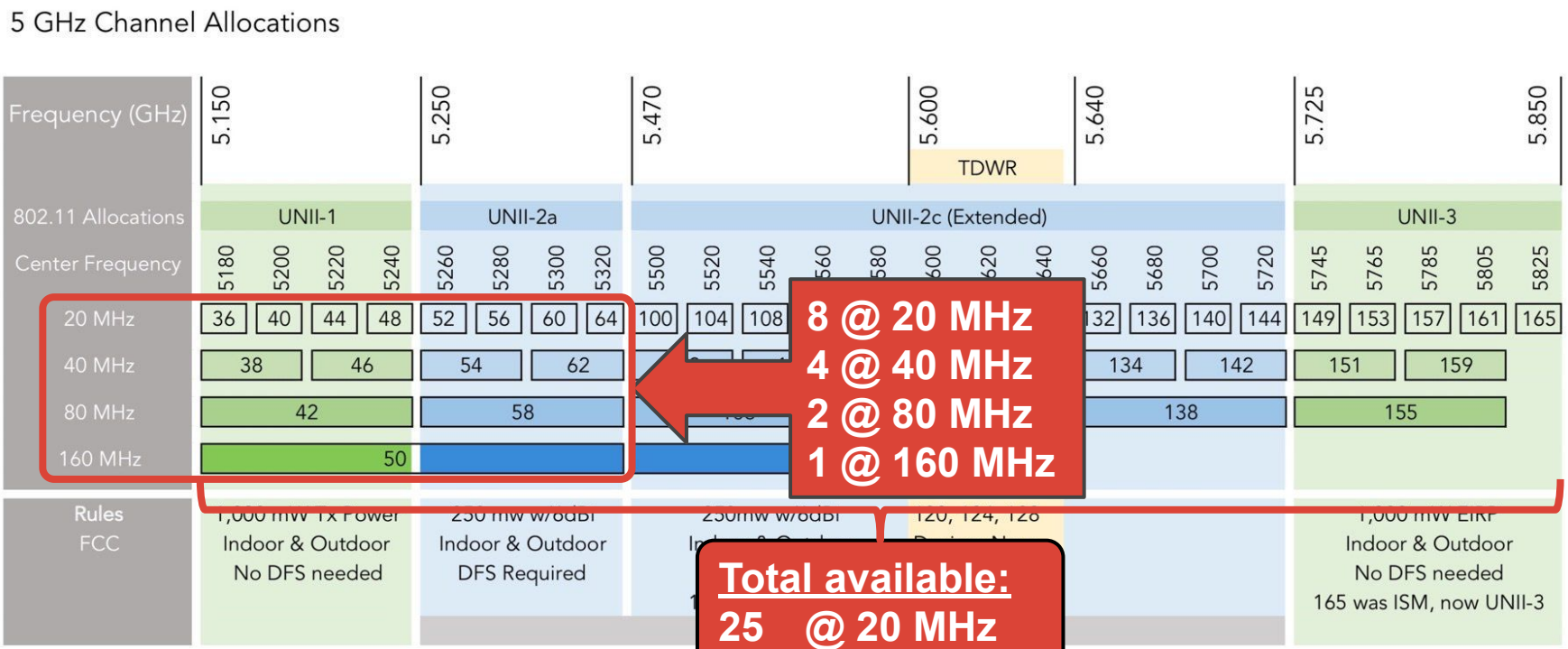


Image source: Keith R. Parsons, wlanpros.com

Metageek inSSIDer

Tool for a quick **Wi-Fi overview**

Access Point Features

Usually, 2 client-serving radios.
(And maybe a sensor.)

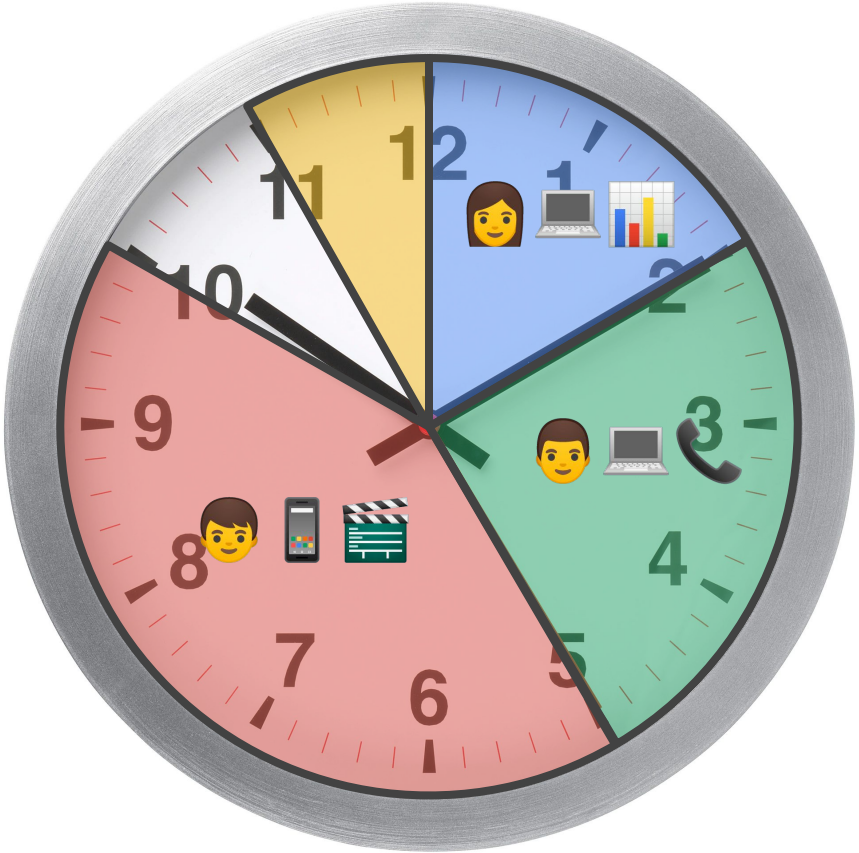
Radio 1	Radio 2
2.4 GHz	5 GHz
2.4 or 5 GHz	5 GHz

Radio 1	Radio 2	Radio 3
2.4 or 5 GHz (Legacy)	5 GHz (Wi-Fi 6 Only)	6 GHz

OFDMA / Future

Maximizing Airtime

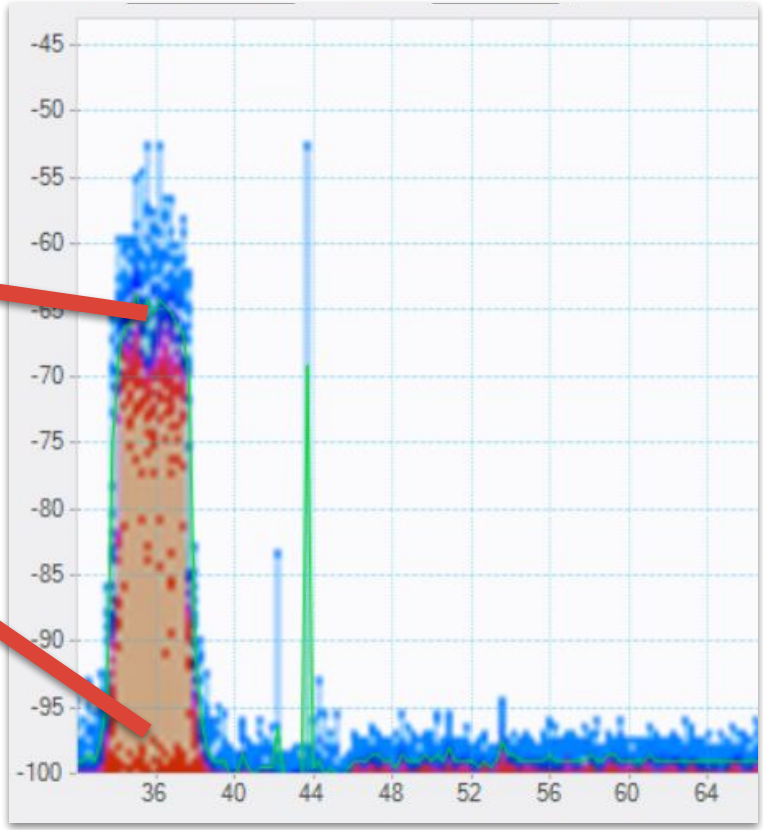
What is airtime?



Signal-to-Noise

Signal (dBm)	-67 dBm
- Noise (dBm)	- (-96 dBm)
= SNR (dB)	**= 29 dB**

Bigger is better!



Metageek Chanalyzer

Visual tool for **spectrum analysis**

metageek chanalyzer

Translating SNR to MCS

A 29 dB SNR should achieve MCS 8.

Signal-to-Noise Ratio		1	2	3	4	5	6	7	8	9	10
802.11b	20 MHz	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1
802.11ag	20 MHz	None	MCS 0	MCS 0	MCS 1	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3
802.11n	20 MHz	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
802.11n	40 MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1
802.11ac	20 MHz	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
802.11ac	40 MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1
802.11ac	80 MHz	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0
802.11ac	160 MHz	None	None	None	None	None	None	None	None	None	None

Modulation Key

- None = Grey
- BPSK = Red
- QPSK = Orange
- 16-QAM = Yellow
- 64-QAM = Blue
- 256-QAM = Green

Signal-to-Noise Ratio		11	12	13	14	15	16	17	18	19	20
802.11b	20 MHz	MCS 2	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
802.11ag	20 MHz	MCS 4	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 5	MCS 6	MCS 6	MCS 7
802.11n	20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5		MCS 6
802.11n	40 MHz	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4		MCS 4
802.11ac	20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5		MCS 6
802.11ac	40 MHz	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4		MCS 4
802.11ac	80 MHz	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS		MCS 3
802.11ac	160 MHz	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2		MCS 3

802.11b

- MCS 0 - DBPSK
- MCS 1 - DQPSK
- MCS 2 - DQPSK
- MCS 3 - DQPSK

Signal-to-Noise Ratio		21	22	23	24	25	26	27	28	29	30
802.11b	20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
802.11ag	20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	20 MHz	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	40 MHz	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7
802.11ac	20 MHz	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8
802.11ac	40 MHz	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7
802.11ac	80 MHz	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6
802.11ac	160 MHz	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6

802.11a/g

- MCS 0 - BPSK
- MCS 1 - BPSK
- MCS 2 - QPSK
- MCS 3 - QPSK
- MCS 4 - 16-QAM
- MCS 5 - 16-QAM
- MCS 6 - 64-QAM
- MCS 7 - 64-QAM

Signal-to-Noise Ratio		31	32	33	34	35	36	37	38	39	40
802.11b	20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
802.11ag	20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11n	40 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
802.11ac	20 MHz	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
802.11ac	40 MHz	MCS 7	MCS 8	MCS 8	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
802.11ac	80 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8	MCS 9	MCS 9	MCS 9	MCS 9
802.11ac	160 MHz	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8	MCS 9

802.11n

- MCS 0 - BPSK
- MCS 1 - QPSK
- MCS 2 - QPSK
- MCS 3 - 16-QAM
- MCS 4 - 16-QAM
- MCS 5 - 64-QAM
- MCS 6 - 64-QAM
- MCS 7 - 64-QAM

Image source: Andrew von Nagy, revolutionwifi.net

Translating MCS to Data Rates

A transmission at MCS 8 would be a data rate of 86.7 Mbps.

Your MCS changes continuously.

802.11ac - VHT MCS, SNR and RSSI

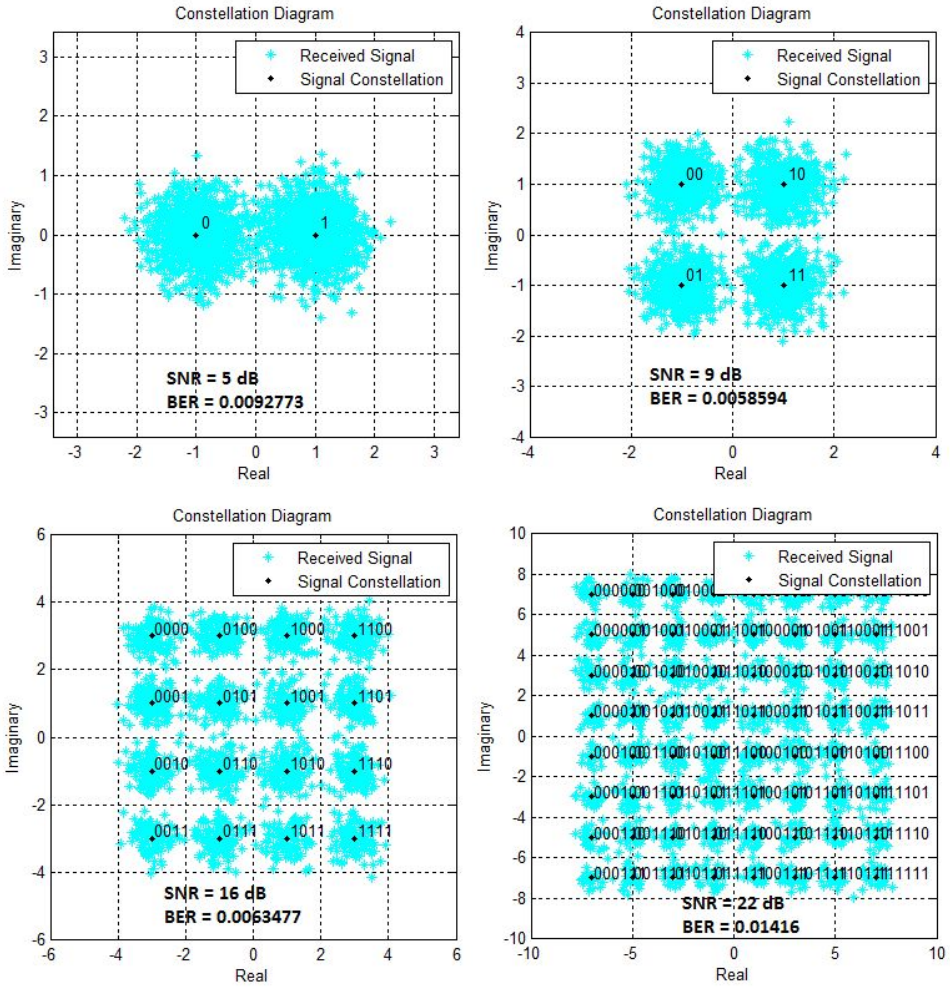
VHT MCS	Modulation	Coding	20MHz				40MHz				80MHz				160MHz			
			Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI
			800ns	400ns			800ns	400ns			800ns	400ns			800ns	400ns		
1 Spatial Stream																		
0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50

?

Image source: Keith R. Parsons, wlanpros.com

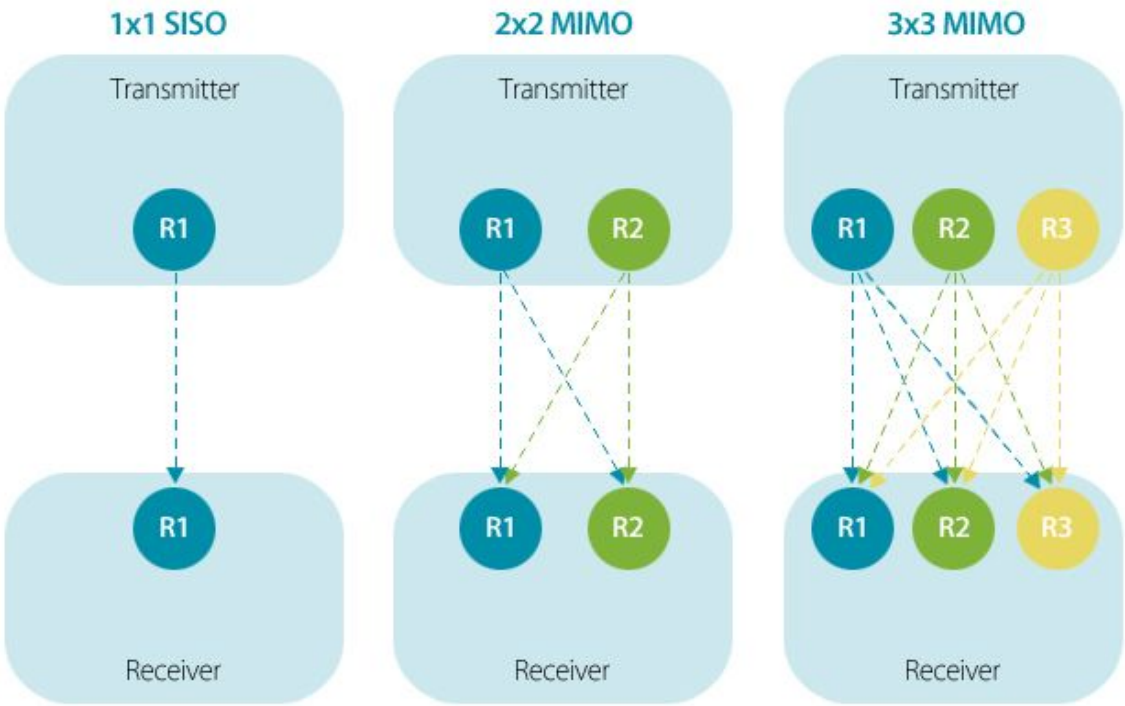
Constellation Maps
(BPSK, QPSK, 16QAM, and 64QAM)

More bits per transmission,
but harder to hit.



Spatial Streams & MIMO

Adding extra radios to the radio chain allows transmission of multiple radio signals at the same time.



How to read a spec sheet:

[Transmitters] x [Receivers] : [Unique Streams]

E.g. 2x2:2, 3x3:2, 4x4:4 ...

Translating MCS to Data Rates

A transmission at MCS 8 would be a data rate of 86.7 Mbps.

Your MCS changes continuously.

802.11ac - VHT MCS, SNR and RSSI

VHT MCS	Modulation	Coding	20MHz				40MHz				80MHz				160MHz			
			Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI
			800ns	400ns			800ns	400ns			800ns	400ns			800ns	400ns		
1 Spatial Stream																		
0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50

Image source: Keith R. Parsons, wlanpros.com

Translating MCS to Data Rates

Both the access point and client in this example have 2 spatial streams.

802.11ac - VHT MCS, SNR and RSSI

VHT MCS	Modulation	Coding	20MHz				40MHz				80MHz				160MHz			
			Data Rate		Min.	RSSI	Data Rate		Min.	RSSI	Data Rate		Min.	RSSI	Data Rate		Min.	RSSI
			800ns	400ns	SNR		800ns	400ns	SNR		800ns	400ns	SNR		800ns	400ns	SNR	
1 Spatial Stream																		
0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
7	64-QAM	5/6	65	72.2	25	-64	135	150	28	-61	292.5	325	31	-58	585	650	34	-55
8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50
9	256-QAM	5/6			31	-57	180	200	34	-54	390	433.3	37	-51	780	866.7	40	-48
2 Spatial Streams																		
0	BPSK	1/2	13	14.4	2	-82	27	30	5	-79	58.5	65	8	-76	117	130	11	-73
1	QPSK	1/2	26	28.9	5	-79	54	60	8	-76	117	130	11	-73	234	260	14	-70
2	QPSK	3/4	39	43.3	9	-77	81	90	12	-74	175.5	195	15	-71	351	390	18	-68
3	16-QAM	1/2	52	57.8	11	-74	108	120	14	-71	234	260	17	-68	468	520	20	-65
4	16-QAM	3/4	78	86.7	15	-70	162	180	18	-67	351	390	21	-64	702	780	24	-61
5	64-QAM	2/3	104	115.6	18	-66	216	240	21	-63	468	520	24	-60	936	1040	27	-57
6	64-QAM	3/4	117	130.3	20	-65	243	270	23	-62	526.5	585	26	-59	1053	1170	29	-56
7	64-QAM	5/6																
8	256-QAM	3/4	156	173.3	29	-59	324	360	32	-56	702	780	35	-53	1404	1560	38	-50
9	256-QAM	5/6																
3 Spatial Streams																		
0	BPSK	1/2	19.5	21.7	2	-82	40.5	45	5	-79	87.8	97.5	8	-76	175.5	195	11	-73
1	QPSK	1/2	39	43.3	5	-79	81	90	8	-76	175.5	195	11	-73	351	390	14	-70
2	QPSK	3/4	58.5	65	9	-77	121.5	135	12	-74	263.3	292.5	15	-71	526.5	585	18	-68
3	16-QAM	1/2	78	86.7	11	-74	162	180	14	-71	351	390	17	-68	702	780	20	-65
4	16-QAM	3/4	117	130	15	-70	243	270	18	-67	526.5	585	21	-64	1053	1170	24	-61
5	64-QAM	2/3	156	173.3	18	-66	324	360	21	-63	702	780	24	-60	1404	1560	27	-57
6	64-QAM	3/4	175.5	195	20	-65	364.5	405	23	-62			26	-59	1579.5	1755	29	-56
7	64-QAM	5/6	195	216.7	25	-64	405	450	28	-61	877.5	975	31	-58	1755	1950	34	-55
8	256-QAM	3/4	234	260	29	-59	486	540	32	-56	1053	1170	35	-53	2106	2340	38	-50
9	256-QAM	5/6	260	288.9	31	-57	540	600	34	-54	1170	1300	37	-51			40	-48

Image source: Keith R. Parsons, wlanpros.com

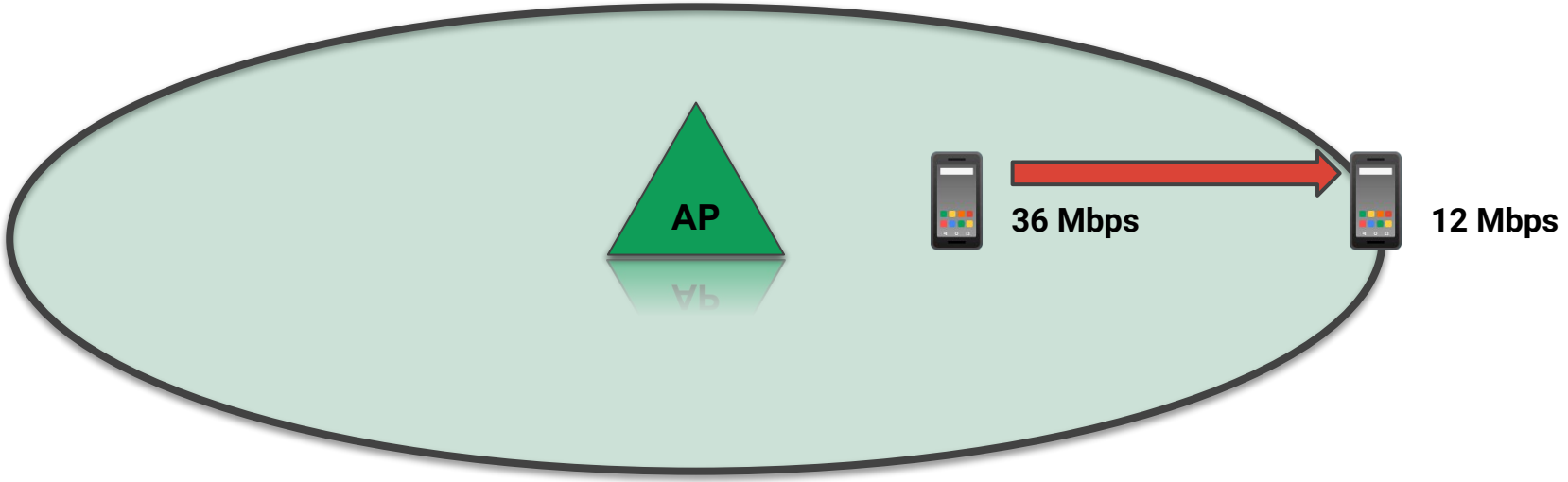
Minimum Basic Data Rate

If your design can guarantee an SNR & data rate, you can set a minimum data rate.

Why? This prevents slow clients from monopolizing airtime.

Also, Disabling 1, 2, 5.5, and 11 Mbps data rates blocks legacy 802.11b clients.

Dynamic Rate Selection & Minimum Basic Data Rates



Management Frames & Overhead

- Retransmissions (from packet loss)
- Acknowledgements (instead of Block Ack)
- RTS and CTS (802.11b clients)
- Beacons (due to # of SSIDs)
- Probes (clients in crisis)
- Broadcast & multicast packets
- Etc...

Improving Available Airtime

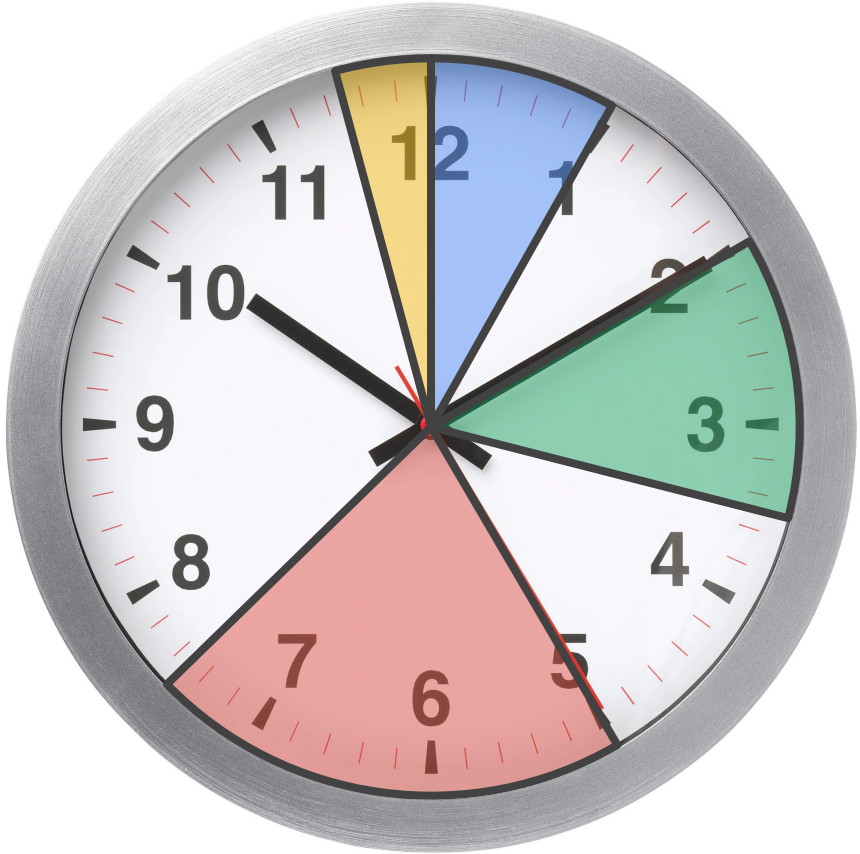
Less noise + higher signal
Higher SNR / MCS rates, & less retries

More spatial streams
Required higher end devices

Wider channels
Less total channels

Reduce overhead
Client compatibility

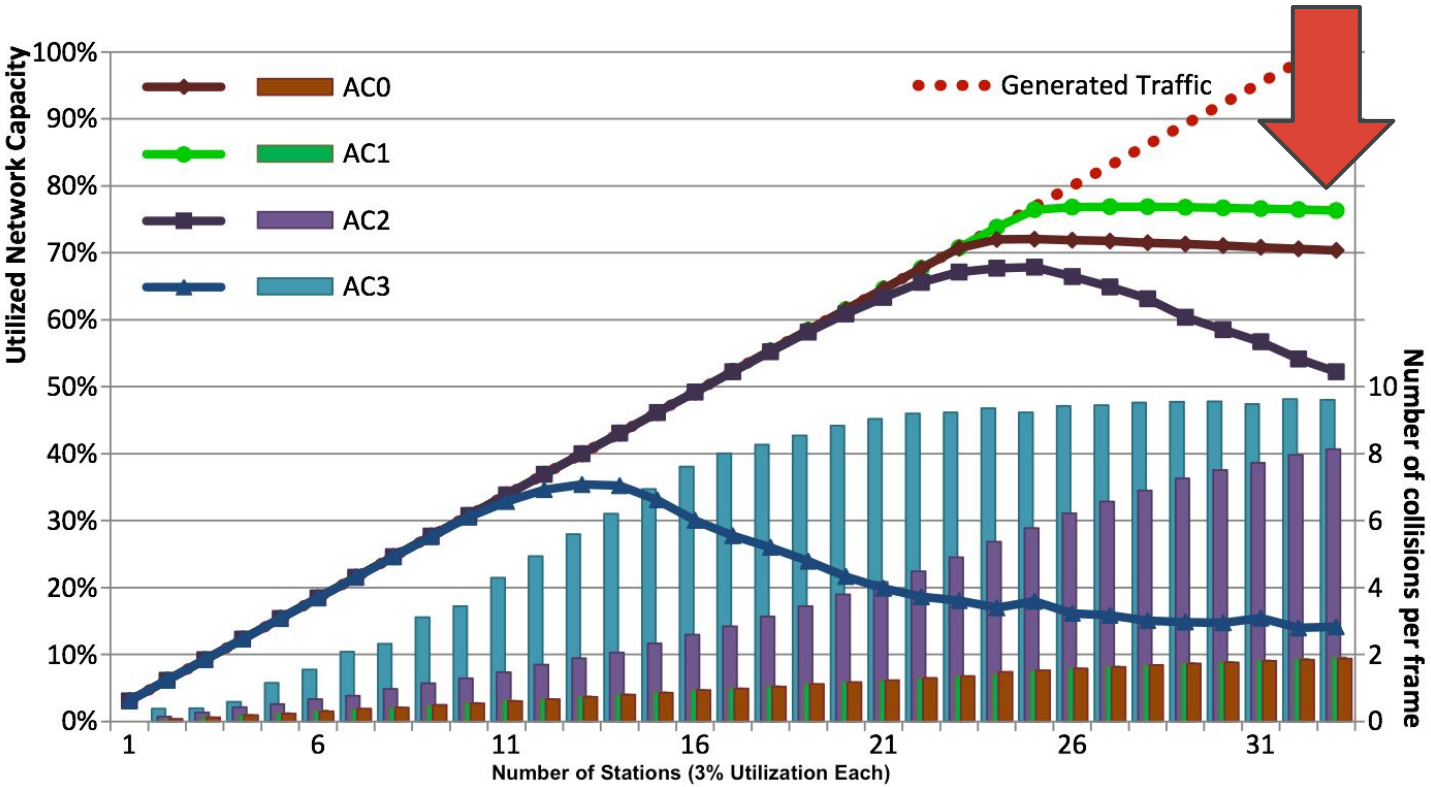
= More available airtime



Metageek Eye P.A.

Visual tool for **airtime** analysis and packet capture of Wi-Fi traffic.

Airtime breaking point



80-90% Data Applications
(Best Effort) (TCP vs. UDP)

50% Mixed Applications
(Data & Voice)

35% Voice Applications
(High Density of Voice Clients)

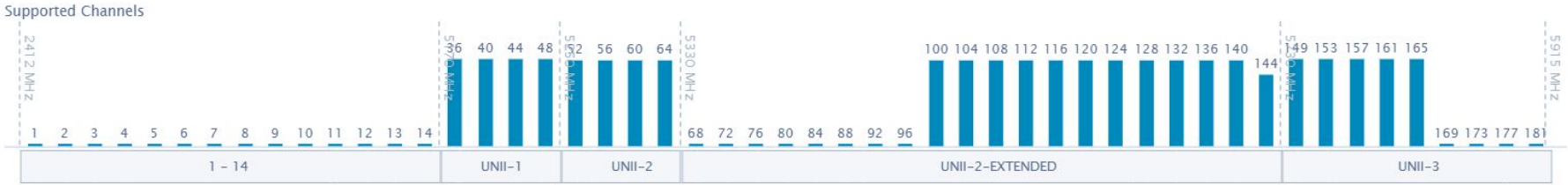
Factors of airtime usage

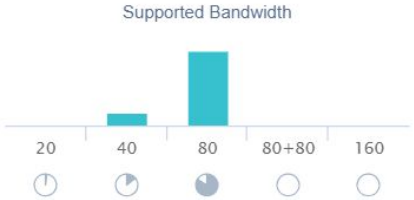
- **Hardware factors:**
  - Wi-Fi standard
  - Spatial streams
- **Environmental factors:**
  - Existing utilization
  - Signal-to-Noise
  - Data rate

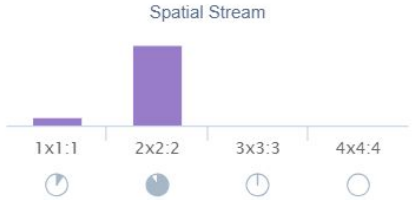
Real Life Client Capabilities

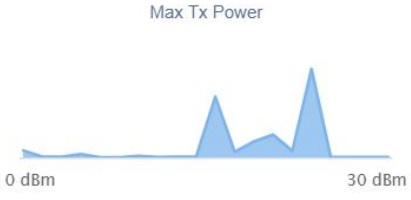
From **05/01/2019 20:12:11** to **05/02/2019 20:12:11** Where's My Data?

MAXIMUM CLIENT CAPABILITIES



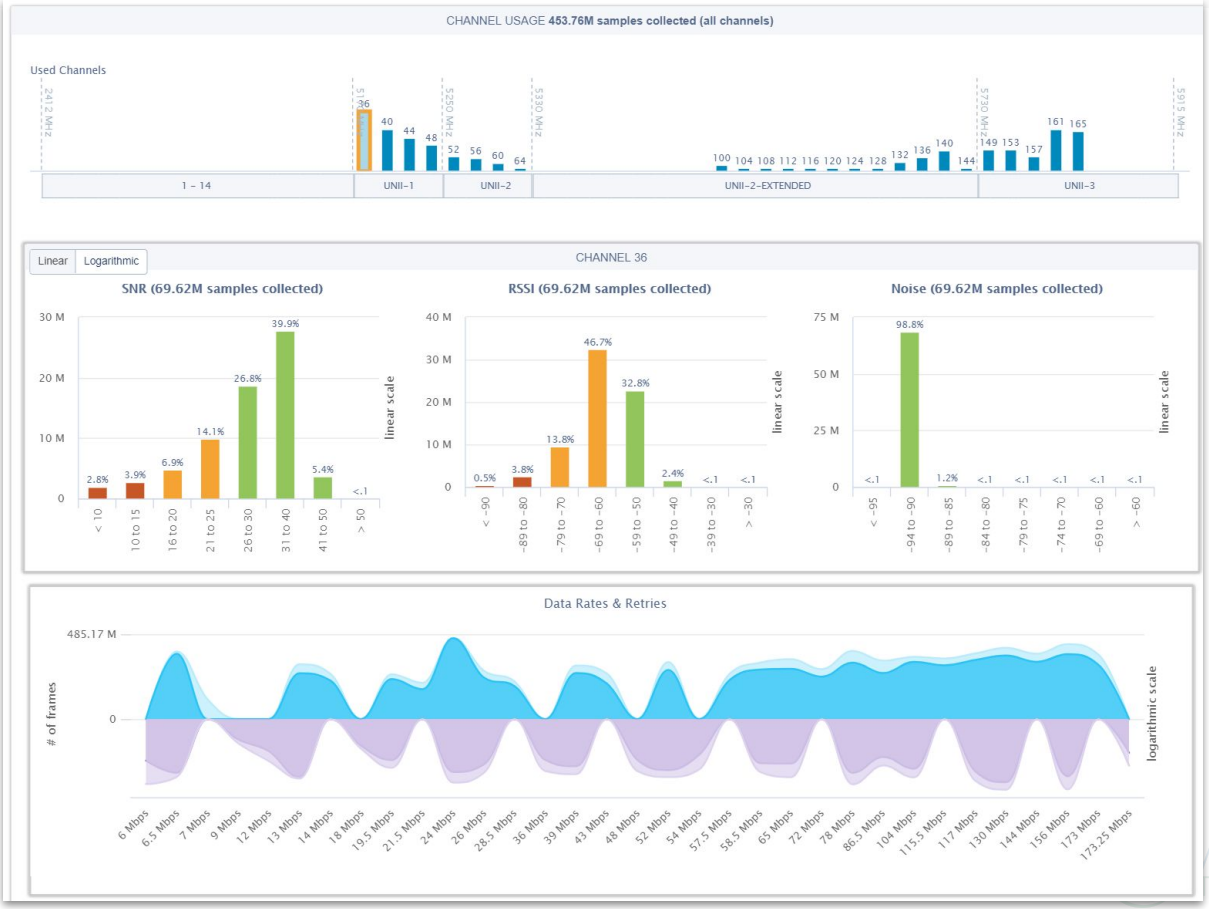




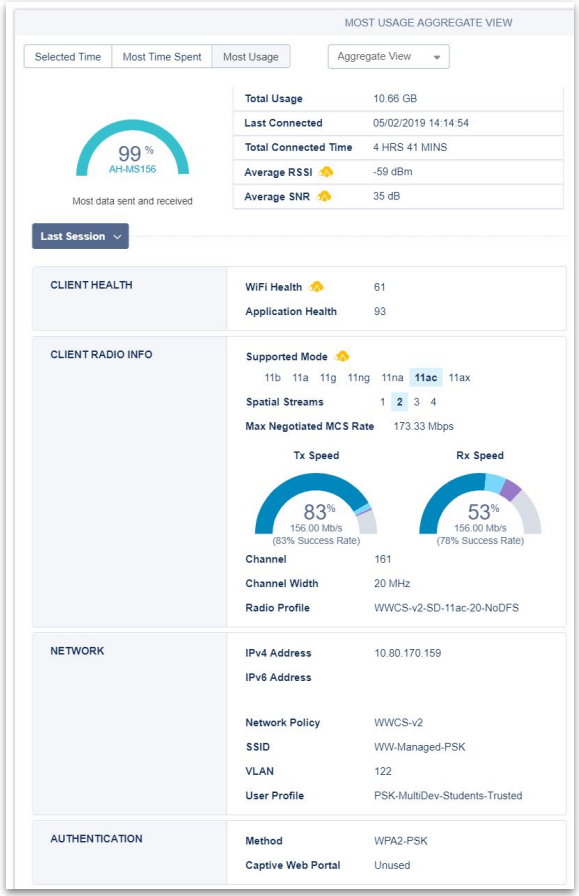


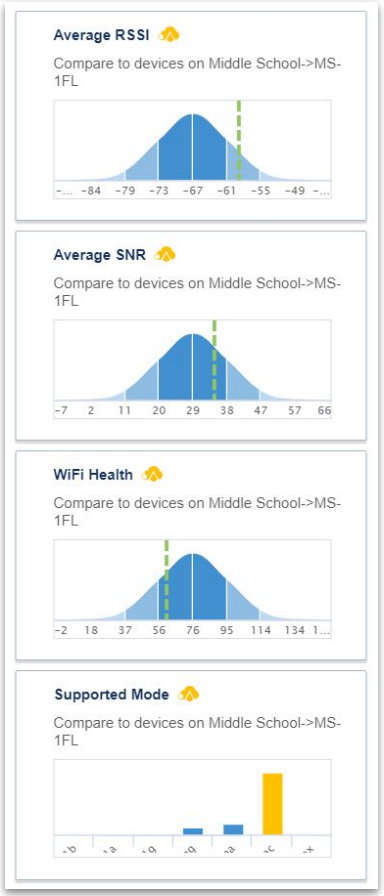
MU-MIMO Capable		Security Support (AKM)		WMM Support		TPC Support		HS 2.0	
Yes: 59	No: 2902	Yes: 0	No: 0	Yes: 2910	No: 51	Yes: 0	No: 0	Yes: 0	No: 0

Real Life Channel Statistics



Real Life Client Stats





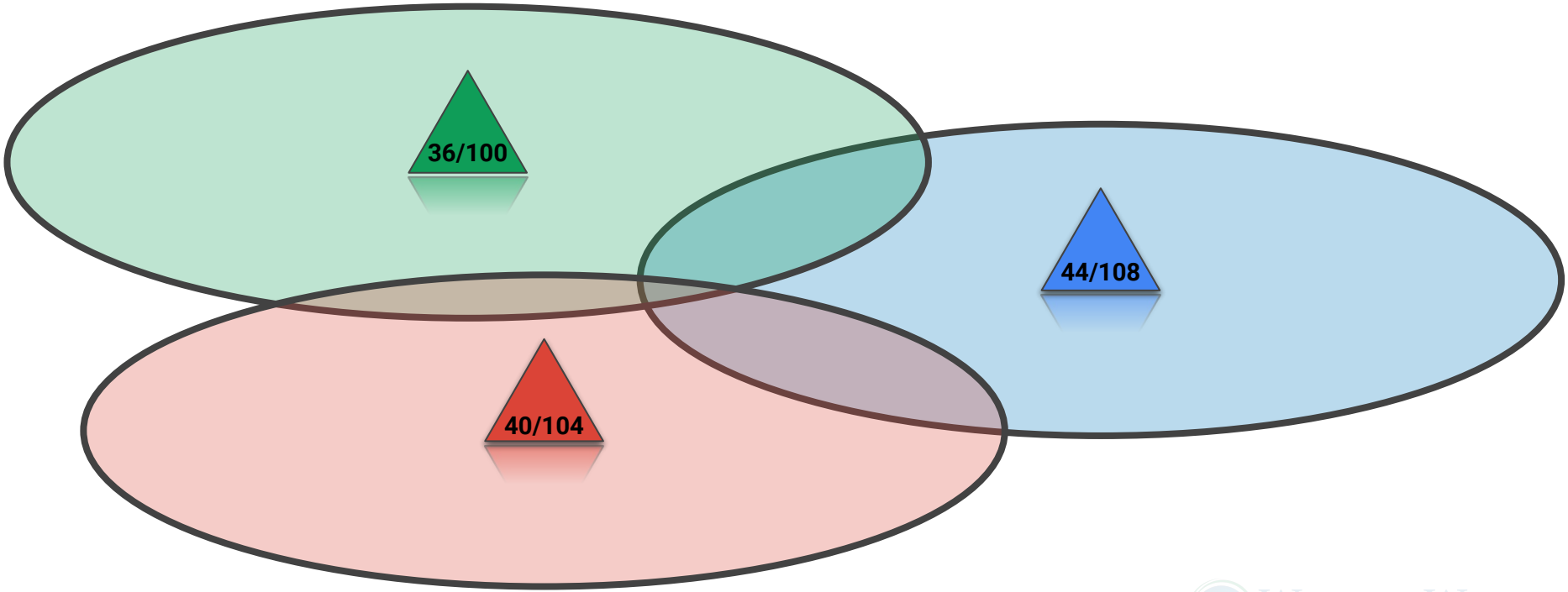
Heading back to the capacity planner...

Goals

- [ ] Provide airtime.
- [ ] Provide coverage.
- [ ] … but not too much.

Access Point Placement

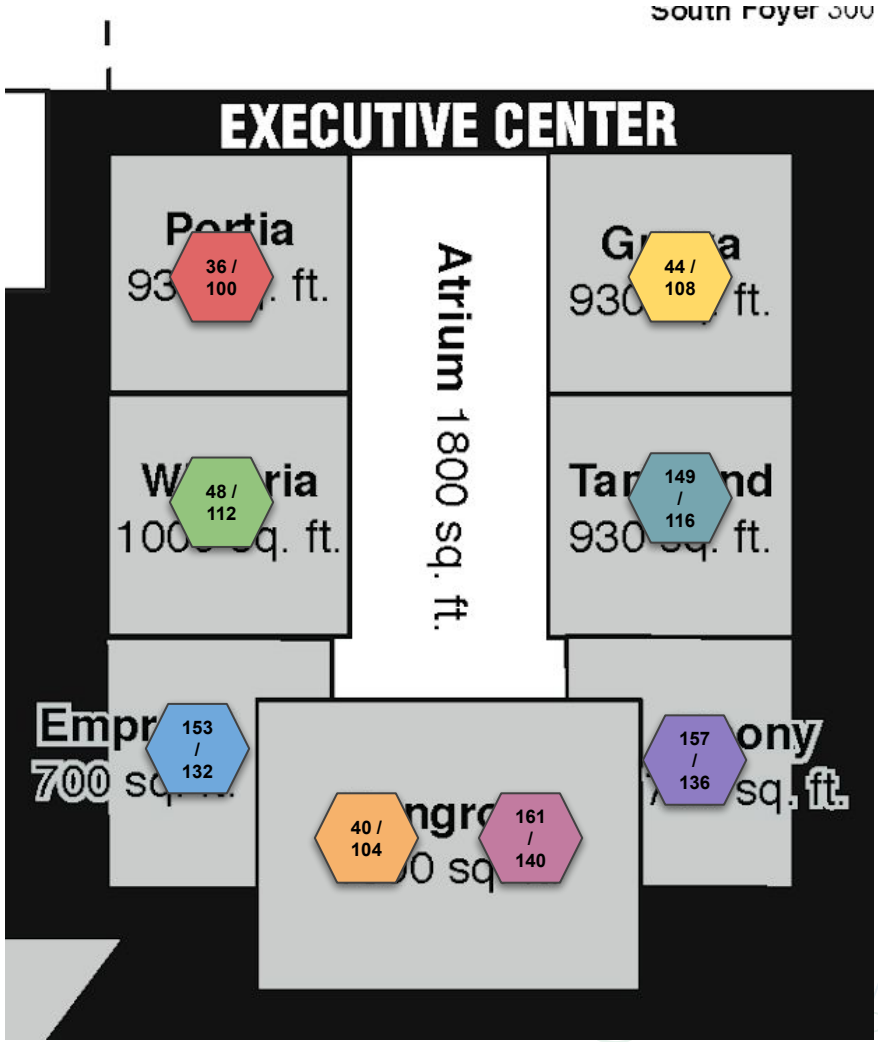
Channel Assignments - 2 per AP



Dual 5 GHz AP Channel Pairings

Combining non-DFS and DFS channels on a single access point to reduce impact of DFS event.

Best practice: 80-100 MHz separation between both channels.



Ranges

Association Range:

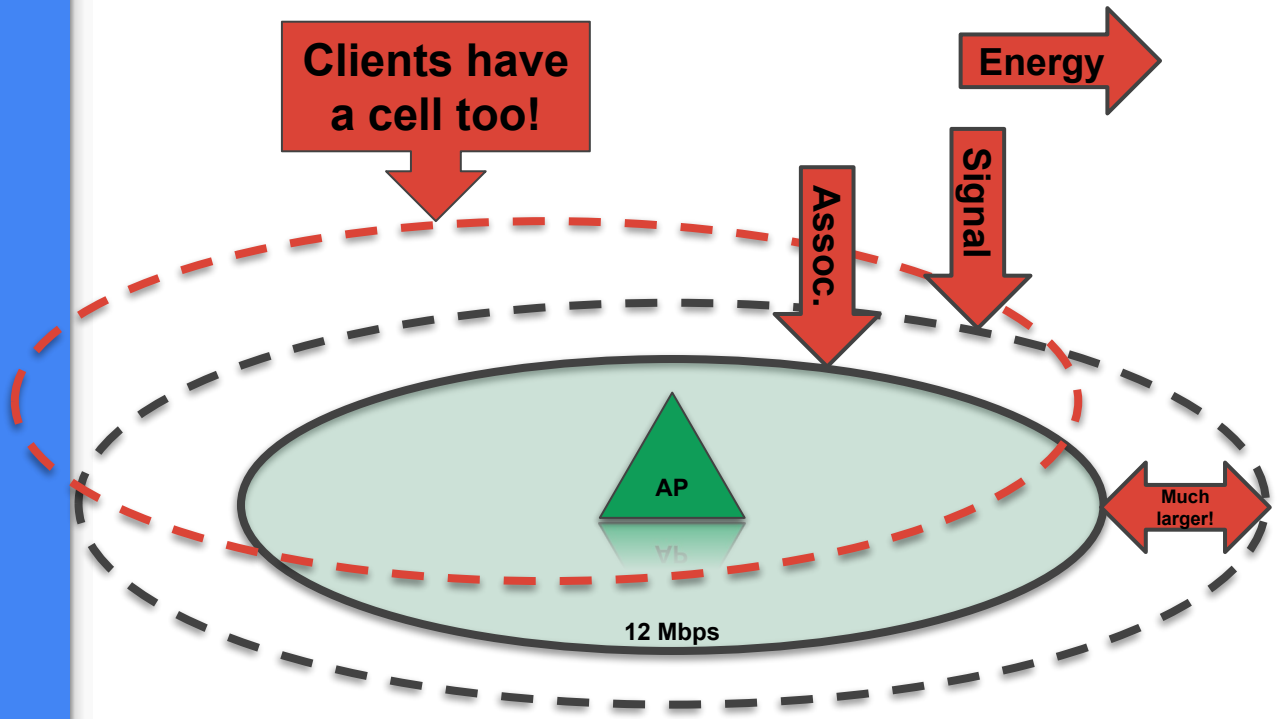
- Controlled by minimum basic data rate
- Forces clients closer to AP

Signal Range (Signal Detect):

- **If the device can decode, it must defer**
- Requires at least 4 dB SNR
- Preamble sent at a much lower data rate: 1 Mbps (2.4 GHz) / 6 Mbps (5 GHz)
- Receive sensitivity of devices vary. APs are very sensitive.

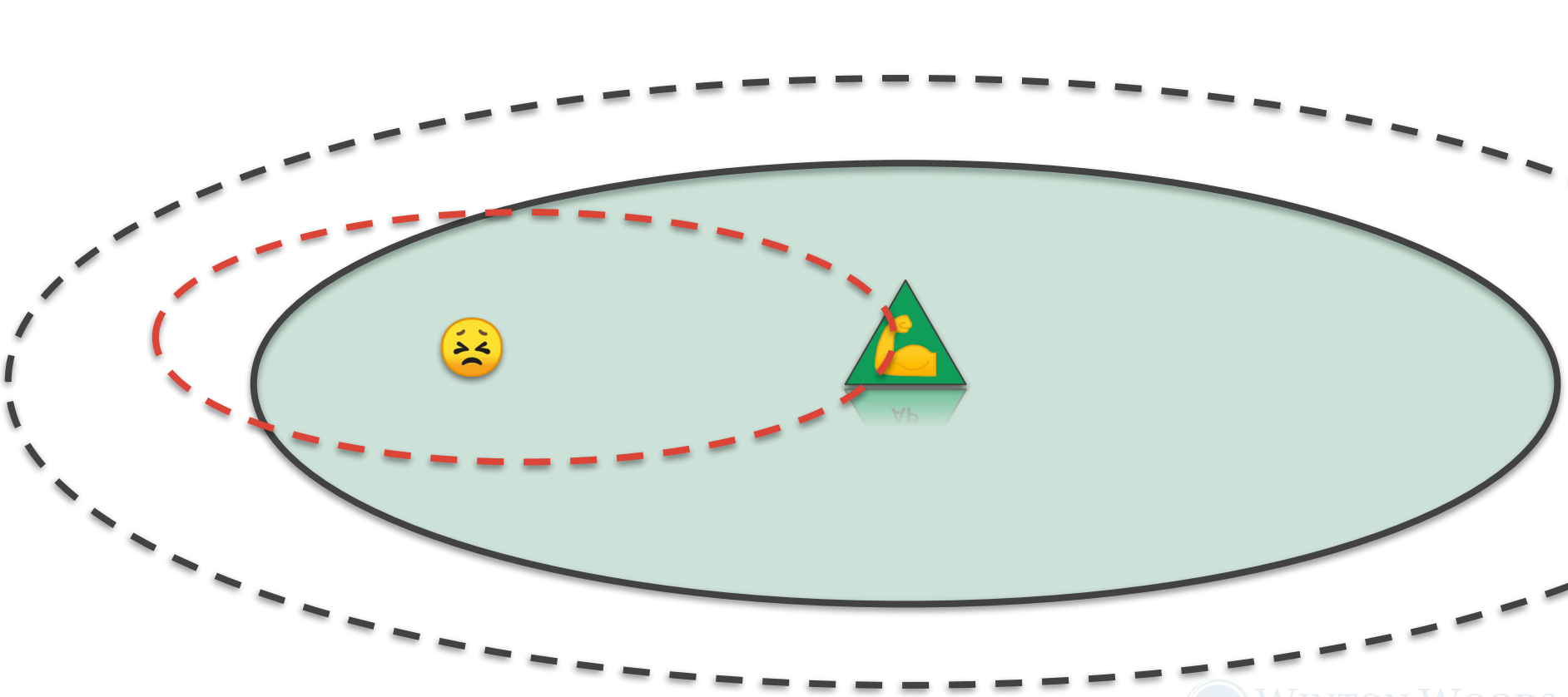
Energy Detect:

- Mechanism for detecting any kind of transmission (non-Wi-Fi interference)
- Requires a high bar: Signal Detect + 20 dB

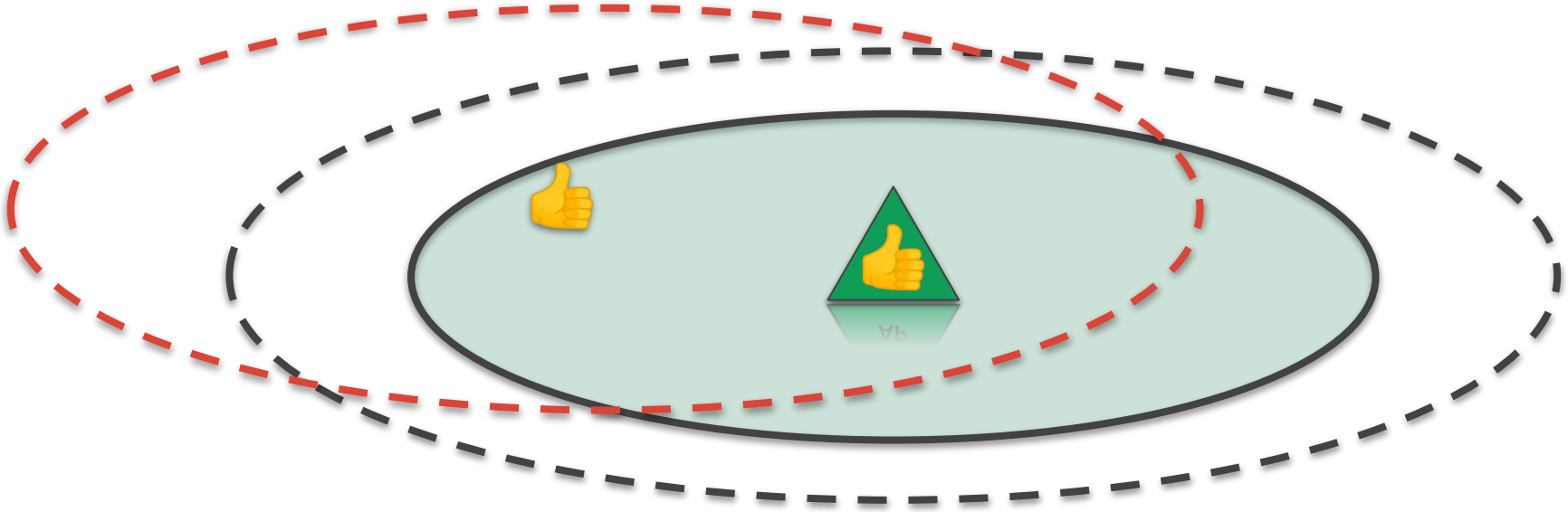


Not to scale.

Transmit Power - Overpowered AP



Transmit Power - Matched



You can’t control the client.

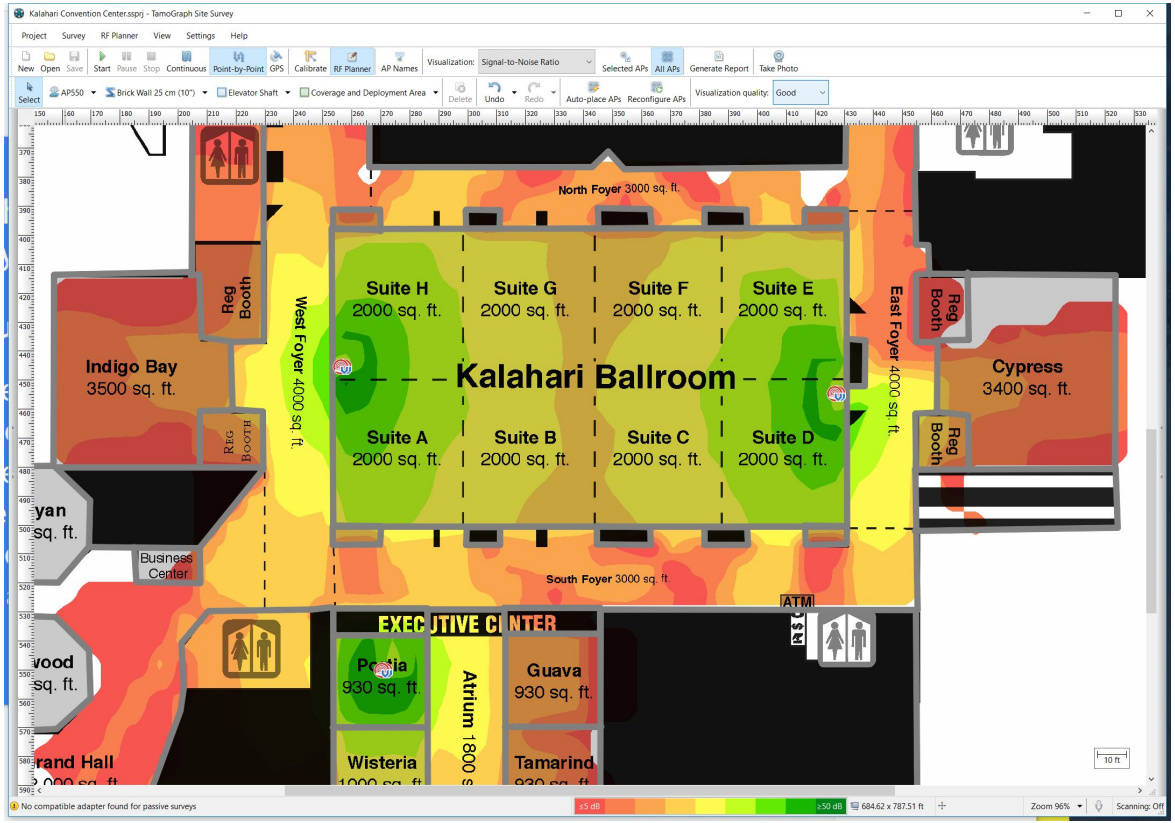
Placing Access Points

- Place enough radios *(access points)* to meet your requirements in coverage and the necessary airtime for your usage, but **don't go overboard**.
- Walls and barriers are **good**. Use them to constrain the signal range so you can reuse a channel sooner.
- Big open spaces (and hallways) are **not ideal**. Multiple APs in the same area, on the same channel, **share airtime**.
- Using **external antennas** allows you to direct your signal range where you need it, but more importantly, to **exclude it from going where you don't.**

Tamosoft Tamograph Site Survey

Two main functions:

1. Estimate coverage and data rates.
2. Validate actual coverage and performance.



Goals

- ☐ Provide airtime.
- ☐ Provide coverage.
- ☐ … but not too much.

Reality Check

If you have a takeaway, this is it.

It’s easy to believe installing APs everywhere will solve your problems.

Remember:
Airtime is per channel, not per access point.

You only have so many channels & you can’t beat physics.

Spectrum is a natural resource, remember?

Wi-Fi is a delicate balance and requires planning.

Goals

- Provide airtime.
- Provide coverage.
- … but not too much.

Some Practical Advice

Don’t do any of this without plenty of testing!

Power over Ethernet

Make sure you have enough available PoE budget on your switches before you replace APs!

SSIDs

SSID	User Type	Description
Guest	Guests	Simple PSK. Captive portal with name / email entry. Times out after 12 hours.
802.1X	Managed & BYOD	RADIUS server authenticating against Active Directory **Managed:** Windows devices authenticate with computer object **BYOD:** User authentication on personal devices
PSK (Multi Device)	Managed	Long complex PSKs deployed with MDM (Chromebooks) to many systems.
PSK (Single Device)	Managed & BYOD	Simple PSKs assigned to a single device, usually standalone devices with no MDM.

User Profiles / Firewalls

	Guest	BYOD	Managed
Firewall - From Device	No discovery protocols No IPv6 No local subnet No VPN apps Only HTTP(S) to internet	No discovery protocols No IPv6 Select local servers only No VPN apps All ports to internet	No discovery protocols No IPv6 Server subnets only No VPN apps All ports to internet
Firewall - To Device	None	None	Server subnets only
QoS	10 Mbps Priority 5	30 Mbps (Staff) 10 Mbps (Students) Priority 10	50 Mbps Priority 15

Traffic Filters / Firewall Rules

Broadcast: Drop

Multicast: Drop (if possible) or convert to unicast

Interstation traffic: Disabled

VLANs and Subnets

Best practice:
<1000 devices per subnet

Device Counts:
Staff/HS/MS: 2 BYOD, 1 Managed
All Others: 1 BYOD, 1 Managed

VLANs:

- Managed or BYOD
  - Staff or Student
    - [Campus] (combine if possible)
      - [Floor] (if needed)
- Guest

Radio Settings

Radios (Both):

- Channel width: 20 MHz
- TX Power: Auto (13 dB max)
- Channel: Auto
- Client TX power control (802.11h): Enable
- Weak SNR Suppress: 10 dB

Radio 1: 5 GHz (No DFS channels)
Radio 2: 5 GHz (All channels)

Data Rates:

- **802.11a:**
  - **Basic:** 24 Mbps
  - **Optional:** 36, 48, 54 Mbps
- **802.11n/ac (MCS rates):** Enabled

Other Enabled Settings:

- **802.11k** - Radio Resource Management
- **802.11v** - BSS Transition Management

Other Tools

Built-in Packet Capture: Some Wi-Fi APs offer capturing packets into Wireshark over the network!

Netscout AirCheck G2: Handheld Wi-Fi tester, great for technicians.

Nuts About Nets RF Explorer: Handheld spectrum analyzer.

Netbeez: Sensors that live in important spaces and continuously test that the network is working.

Ekahau Sidekick & Site Survey: Top of the line hardware and software for designing Wi-Fi networks.

And all the stuff I've already shown...

Thanks!